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Characterization and Correction of Multispectral Resolving Filter-On-Chip CMOS-Sensor-Systems for Shape, Color and Composition Measurements

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Abstract. Aim of the paper is to show which increased capabilities are offered by the application of multispectral resolving Filter-On-Chip CMOS-Sensor-Systems for shape, color and spectral measurements. The paper will show a generalized method how these new Sensor-Systems can be characterized through measurements and how they can be applied for selected measurement tasks where the parallel acquisition of shapes, colors and compositions matters.
Furthermore, it will be shown how an extended system characterization for multispectral resolving Filter-On-Chip CMOS-Sensor-Systems can be realized methodically to determine sensor-system caused systematic deviations influenced by illumination, optics, multispectral filter matrices and the CMOS-Sensors itself and how the results can be used for the algorithmically correction to overcome the sensor-system caused systematic deviations.

1. Introduction

Photonic micro sensing and digital image processing are key functions to measure and control the product and service qualities - convenient, reliable and affordable. To meet the growing expectations concerning the qualities of products and services in industry, biomedicine, environment, security and administration, miniaturized photonic micro sensors are now available for simultaneous acquisition of shapes, colors and compositions of liquids, solids and gases.
The latest developments in photonic micro sensor systems enable simultaneous recording of those information with specialized multispectral Filter-On-Chip CMOS-Sensors. Sensor-Systems equipped with these sensors can be named as multi- or hyperspectral snapshot cameras.

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2. Multispectral Resolving Filter-On-Chip CMOS-Sensor-Systems

To realize a simultaneous acquisition of shapes, colors and compositions with one single image, so-called multispectral Filter-On-Chip (FOC) CMOS-Sensors can be used. These sensors are characterized by spectral sensitive filters which are applied directly on the CMOS-Sensor pixel in a matrix which is multiplied in the x- and y-direction over the entire CMOS-Sensor surface.

Current multispectral FOC CMOS-Sensors, available on the market, are using 4, 9, 16 up to 25 different spectral sensitive filters in the visible (figure 1) [1] [2], the near infrared or in the short-wave infrared. The spectral sensitive filters applied in the repeating filter matrix on the CMOS-Sensor working in accordance to the Fabry-Pérot filter principle. The resonator length of the applied filter determines its spectral sensitivity.

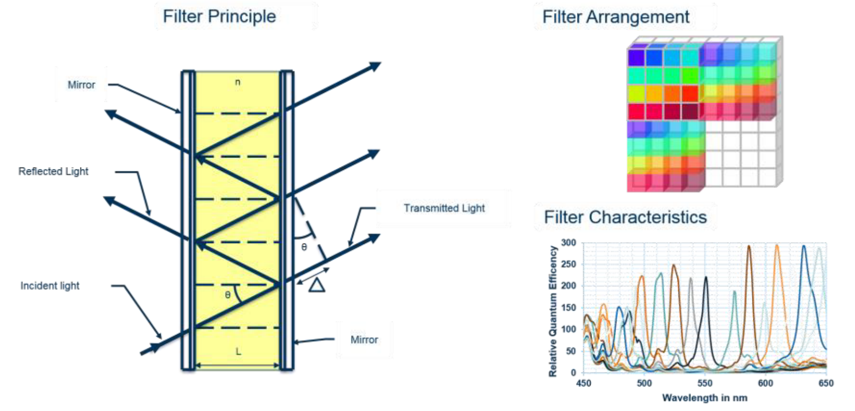

Figure 1. Example for the physical mode of operation of multispectral resolving Filter-On-Chip CMOS-Sensors

For the realization of the multispectral Filter-On-Chip CMOS-Sensors two technologies are applied. First approach is a monolithic approach where the filters are directly applied on the CMOS-Sensor surface. Second approach is a hybrid approach where the filters are applied on a separate substrate and the filter equipped substrate is afterwards arranged and applied on the CMOS-Sensor surface.

The monolithic approach is commonly usable for high volume mass production. The hybrid approach is usable even for low volume production. Also with the hybrid approach the realization of different spectral filter characteristics for same kind of CMOS-Sensors can be done. Furthermore, the application of micro lenses on the applied CMOS-Sensor is possible.

3. Measurement Characterization of Filter-On-Chip CMOS-Sensor-Systems

Multispectral Filter-On-Chip CMOS-Sensor-Systems are influenced by specific aberrations: Inhomogeneities of the spectral filter materials by micro-technological processing constraints and electronic processing errors caused by crosstalk, leakage, harmonics and temperatures (figure 2) [3]. Furthermore, the illumination and the optical properties of the lenses in front of the FOC CMOS-Sensor will have an impact on the effective sensor responses.

To tackle these issues the multispectral FOC CMOS-Sensors should be characterized by an extended sensor model through an extended sensor characterization based on the EMVA1288 standard [4]. The EMVA1288 standard will be extended by multispectral conditions and temperature influences.

The following sensor-specific properties should be evaluated under multispectral illuminations with different angles of incidence of the used illumination and under different temperatures:

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- Spectral sensitivity,
- Saturation,
- Linearity,
- noise (temporal noise, photon noise, dark noise / dark current, readout, quantization noise),
- dynamics,
- artefacts (bad pixels, hot pixels and crosstalk) and
- inhomogeneities (fixed pattern noise, PRNU, DSNU).

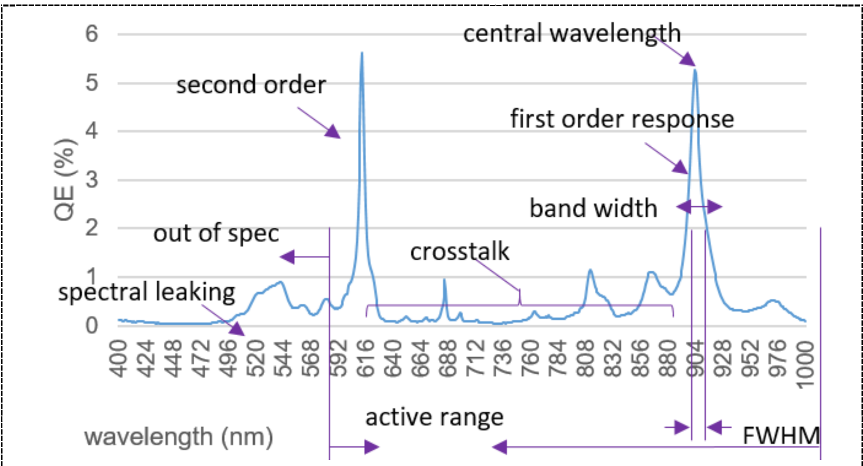

Figure 2. Example for multispectral FOC CMOS-Sensor pixel filter properties.

The evaluated results are then used to develop a robust and repeatable extended sensor model for FOC CMOS-Sensors to overcome the above-mentioned deviations by illumination, optics, multispectral filter matrices and the CMOS sensors itself. The extended system characterization can be performed with monolithic and hybrid manufactured multispectral Filter-On-Chip CMOS-Sensor-Systems.

Thus, these new sensor solutions are representing the next step in the development of photonical sensor-systems. Therefore, a standardized characterization and interpretation of the sensor properties should be developed. To interpret the sensor raw data, it is important to understand and measure the above-mentioned properties.

4. Algorithmic Correction Filter-On-Chip CMOS-Sensor-Systems

The following section provides a general method for the usage of multispectral resolving Filter-On-Chip CMOS-Sensor-Systems in the visible wavelength range from 380 nm to 780 nm. Usage means the performed metrological characterization, the derived correction of the sensor data, the also derived sensor value extension and the ready to use sensor data for final application (figure 3).

Through the measurement characterization of the spectral, optical and electrical properties of the Sensor-System a sensor value correction and extension model can be derived. By the usage of the characterized spectral properties a correction matrix for the pixel reflectance values and their intensity differences can be calculated to minimize spectral crosstalk [5]. Afterwards a Pixel-Separation and Fixed-Pattern-Correction for the alignment of the separated multispectral sub-images among themselves can be derived from the characterized optical Sensor-System properties. Multispectral channel specific properties can be derived through the characterized electrical properties during measurement characterization.

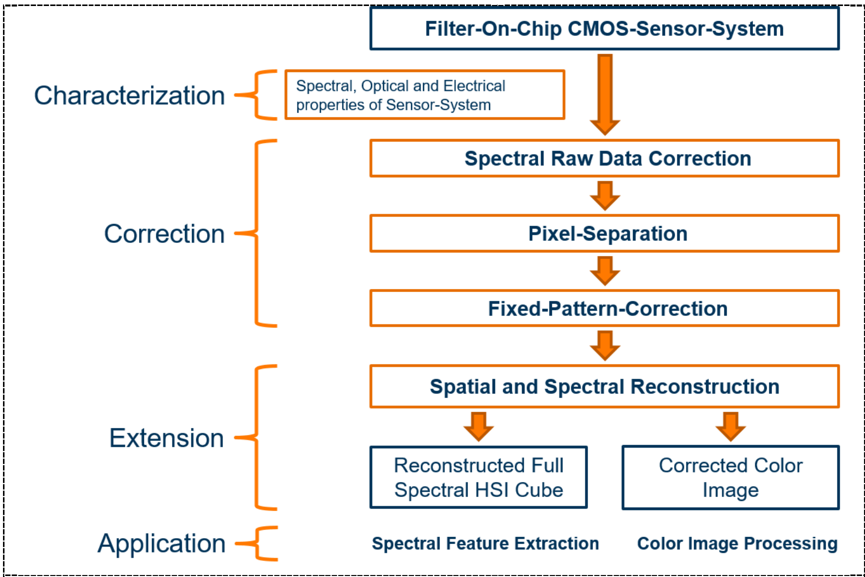

Figure 3. Algorithmic correction model for Filter-On-Chip-Sensor-Systems

By the usage of the characterization results as well as methods and algorithms for reconstruction the spatial and spectral values of the sensor-system can be reconstructed from the multispectral data of a limited number of channels on this basis of continuous spectral distributions. Typical reconstruction methods can be categorized into linear and nonlinear techniques. Examples of linear technique are Moore–Penrose pseudo-inverse, Wiener estimation and PCA. Nonlinear estimation methods have more variations, but some of them can be considered as combinations of linear estimations. Some of the reconstruction methods require an iterative process, such as the ones based on compressive sensing theory [6].

5. Summary & Conclusions

Multispectral resolving Filter-On-Chip CMOS-Sensor-Systems provide a new approach for Multi-/Hyperspectral Imaging. It has been shown that there is a need for an extended system characterization especially based on EMVA1288 standard for multispectral Filter-On-Chip CMOS-Sensor-Systems. The extended system characterization will be used to develop an extended sensor model to get robust and corrected sensor data. The full paper will show how an extended system characterization based on EMVA1288 standard can be applied and how this additional information can be used to derive a more robust sensor model to improve the capabilities of multispectral Filter-On-Chip CMOS-Sensor-Systems.

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